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TECHNICAL NOTES.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

No. 89.

THE CHOICE OF THE SPEED OF AN AIRSHIP.

By Max M. Munk.
National Advisory Committee for Aeronautics.

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By Max M. Munk.

Superior navigation can increase considerably the range of an airship and improve its economy. One of the most important problems of navigation is the question, which speed to choose at every moment and in which direction to steer the airship. The answer depends on many considerations, but for usual conditions it is possible to give some fairly simple rules which may be of advantage if reasonably applied.

It is desirable first of all to keep always that absolute course with respect to the earth's surface which gives the shortest absolute distance between starting point and destination of the voyage, whatever the strength and the direction of the wind may be. This is impossible of course in the rare cases that the side wind exceeds the greatest speed of the airship; and, if the contrary wind is strong enough it may happen that the navigator is able to hold the airship on her course, but that it is driven backwards. Under ordinary conditions, however, the airship ought to be able to keep her course and to advance in it. The path relative to the wind is then the relative path of shortest distance, under the condition that the wind is constant during the entire voyage, and hence the course is the most favorable. If the wind changes but slightly, the distance relative to the wind will not be materially increased. For extreme changes of the side wind this may be different, but the navigator cannot know in general in what way the wind is going to change; the probability that it remains constant is greater than any other, and any other assumption is in most cases quite arbitrary. The case of constant wind is the most important one and simplest, therefore, and should be discussed.

In clear weather the navigator is well able to determine the absolute course. Over land he can observe the relative motion of objects or lights, and over sea he can drop down any floating and visible object, luminous at night, and observe it. The floating object assumes the velocity of the water and does not stay at its place absolutely, it is true; but the motion of water is small when compared with the speed of the airship and is moreover known in many cases and can be taken into consideration. If the air is foggy, however, the method of observing objects beneath the airship is no longer possible. It may be that the previous method can be replaced then by other methods, astronomical, if the sky is visible, or electrical.

Now let the "Speed" V, denote the velocity of the airship with respect to the air, as measured by the speed meter. The components of this speed parallel and at right angle to the absolute course may be denoted V_1 and V_2. The absolute wind velocity may be denoted by W and may be resolved into the two components W_1

along the course, W_2 the side wind, at right angles to the absolute course.

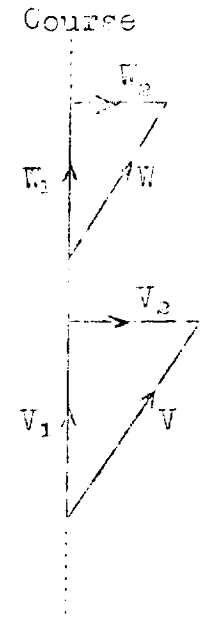


Fig. 1.

It can easily be seen that the condition for keeping the absolute course is $V_2 + W_2 = 0$; that is to say, that the speed at right angle to the course has to be equal and opposite to the side wind. The question of the absolute side speed is thus settled and I proceed to the chief problem, that is the magnitude of the speed of the airship.

The favorable speed of an airship is chiefly determined by the condition of the least consumption of fuel per unit of travelled distance, although other conditions come into play. The resulting rules depend on the character of the wind; whether it is favorable, that is nearly in the direction of travel, side wind or contrary wind, and they depend on the variability of the efficiency of the engine-propeller units. With respect to this last consideration two main cases are to be distinguished.

Within a wide range of speed the efficiency can be supposed to be practically constant. In this case the consumption of fuel per unit of time is proportional to the cube of the speed, that is, proportional to $(V_1^2 + W_2^2)^{3/2}$ and the traveled distance during this time is $(V_1 + W_1)$. Hence the consumption per unit of traveled distance is proportional to $\frac{(V_1^2 + W_2^2)^{3/2}}{V_1 + W_1}$. In this expression W_1 and W_2 are the two components of the wind and are therefore given; the only variable is then V_1. The condition of the minimum consumption per unit of traveled distance is that the differential quotient with respect to this variable is zero, that is

$$\frac{d}{dV_1}\frac{(V_1^2 + W_2^2)^{3/2}}{V_1 + W_1} = \frac{3(V_1^2 + W_2^2)^{1/2}\, V_1 (V_1 + W_1) - (V_1^2 + W_2^2)^{3/2}}{(V_1 + W_1)^2} = 0$$

$$V_1^2 + \frac{3}{2} V_1 W_1 - \frac{1}{2} W_2^2 = 0$$

$$V_1 = -\frac{3}{4} W_1 \pm \sqrt{\frac{W_2^2}{2} + \frac{9}{16} W_1^2}$$

The expression is still too complicated for practical application. Considering that the constancy of the efficiency is only approximate, that the wind components are variable too, and never exactly known, that moreover the consumption in the neighborhood of its minimum is hardly noticeably increased, the expression may be simplified without diminidhing the usefulness of the result. The simplification consists in replacing 1/2 the factor of the first term under the radical by 9/16, thus increasing the value of the square root by some percent.

$$V_1 = -\frac{3}{4} W_1 \pm \frac{3}{4} W = \frac{3}{4} (\pm W - W_1)$$

If the side wind is feeble, V_1 is practically the velocity V, and W_1 may be replaced by W. So that

$$V = -\frac{3}{4} W \pm \frac{3}{4} W$$

There are two cases, therefore, to be considered:

1. $$V = -\frac{3}{4} W - \frac{3}{4} W = -\frac{3}{2} W$$

Hence W has a negative value, i.e., it is a contrary wind; and the most favorable speed of the airship is three halves of this contrary wind. This makes the speed of the airship over the earth one-half the magnitude of the wind.

2. $$V = -\frac{3}{4} W + \frac{3}{4} W = 0$$

Hence the wind is in the direction of the airship's course, and obviously, the most economical procedure would be not to consume any fuel, which is what $V = 0$ means. The speed over the earth is then simply the speed of the wind.

If, on the other hand, the wind is not strong, but on the whole is a contrary one, we cannot neglect the side wind.

$$V_1 = \frac{3}{4}(W - W_1)$$

i.e., the velocity should be three-fourths of the sum of the magnitude of the wind and the contrary wind.

Consider as the second assumption, that the efficiency is not constant, but, as is approximately the case at small speeds, that the efficiency is proportional to the speed V. The specific consumption is then proportional to

$$\frac{V_1^2 + W_2^2}{V_1 + W_1}$$

and the minimum condition is now

$$2V_1 (V_1 + W_1) - (V_1^2 + W_2^2) = 0$$

$$V_1^2 + 2V_1 W_1 - W_2^2 = 0$$

$$V_1 = - W_1 \pm \sqrt{W_2^2 + W_1^2}$$

$$V_1 = \pm W - W_1$$

Without any side wind the most favorable speed has to be twice that of the contrary wind. The expression differs from the one obtained before only by a factor; it is 4/3 times as great. The general character of the condition remains as before.

It is unnecessary to calculate the condition for more cases. Obviously, for a smaller variability of the efficiency, the factor can be taken between .75 and 1. It is not necessary to have the absolute minimum, nor is the variability known exactly enough in every single case. And even if it were so, the navigator has no time to calculate the speed with long formulas and with the help of a calculation machine. I wish simply to give him a fairly simple rule which he can keep in mind, and which will give him a hint as to the right speed. For the application of the results it is only left to decide down to what speed the efficiency can be considered to be constant. With the usual propellers and under ordinary present conditions, 65 mi/hr may be considered to be the lower limit. For lower speed, the quick arrival at the destination rather than a small consumption of fuel becomes more and more the consideration of the pilot. 50 mi/hr may be the absolute minimum speed; that depends on the circumstances. The following rules result from the investigation thus finished:

I. Always keep the absolute course and steer at such an angle with reference ~it as to neutralize the side wind.

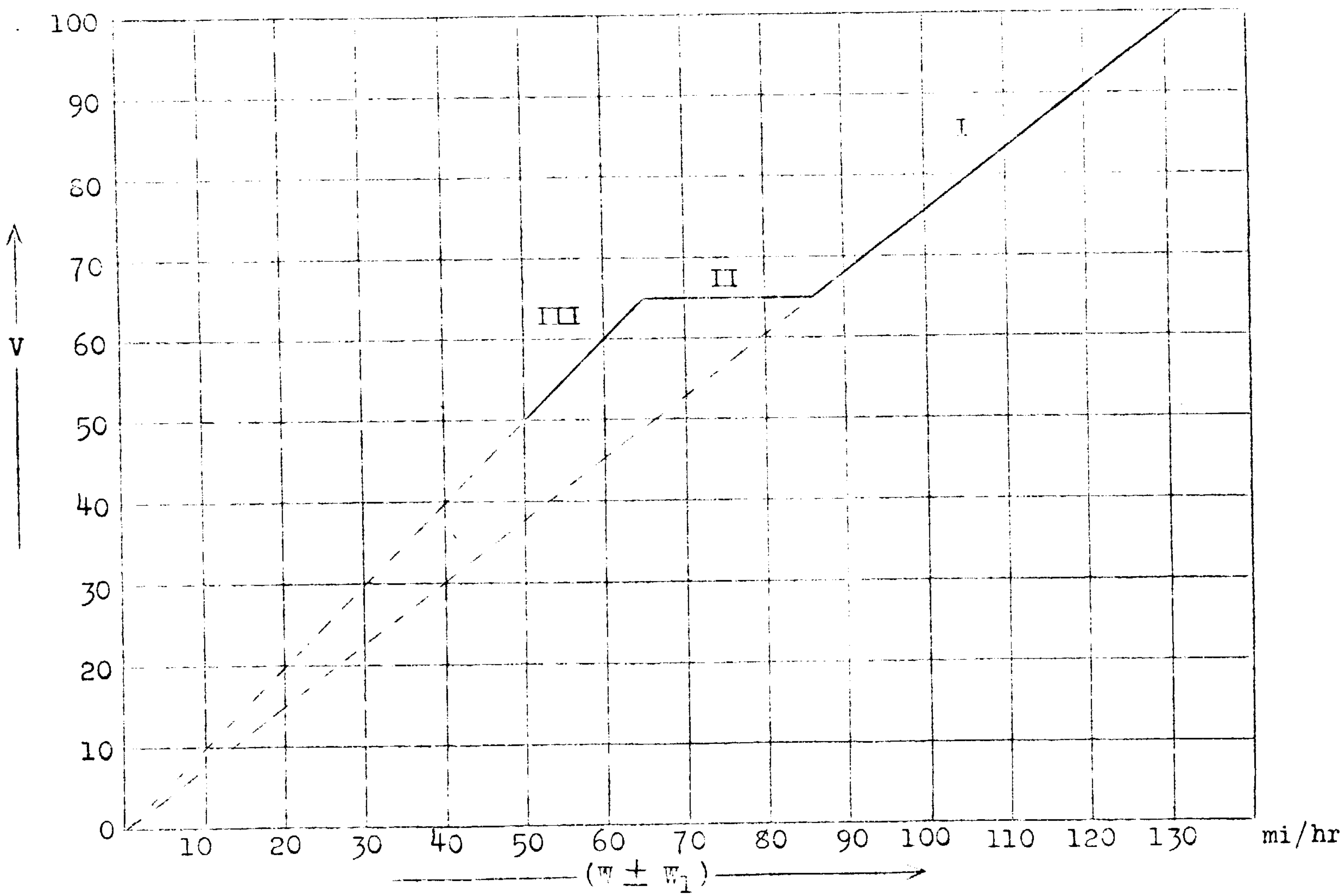
II. Strong (ry wind. Take a speed 1-1/2 times the velocity of the wind.

III. General rule. Take the velocity of the wind and the velocity of the course component of the wind. Add them together if the wind has a contrary component, but subtract them from each other if the wind has a favorable component. This sum or difference determines the speed of the airship relative to the air to be chosen.

(a) The sum or difference exceeds 86 mi/hr. Choose the speed 3/4 of it.

(b) The sum or difference lies between 86 mi/hr and 65 mi/hr. Choose the speed 65 mi/hr.

(c) The sum or difference is smaller than 65 mi/hr. Do not choose the speed smaller than it; the sum or difference gives directly the speed of smallest consumption of fuel.



Speed of minimum consumption.